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CODED-WIRE TAG STUDIES ON

PRINCE WILLIAM SOUND SALMON, 1992

by

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STATE/FEDERAL NATURAL RESOURCE RESTORATION STUDY
FINAL REPORT

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EXECUTIVE SUMMARY

This report documents Restoration Study R60A, one of the projects designed to restore the pink salmon *Oncorhynchus gorbuscha* resource of Prince William Sound to its pre-spill status. Coded wire tags applied in 1991 at four hatcheries in Prince William Sound, the W. Noerenberg, Cannery Creek, A. F. Koernig and Solomon Gulch facilities, were recovered in the commercial catch of 1992 and used to provide inseason estimates of hatchery contributions. The estimates were used by fishery managers to target the numerically superior hatchery returns, and thus to reduce the pressure placed upon oil-damaged wild stocks. Three methods of inseason estimation were tried, each being a compromise between accuracy, precision and time required to produce the estimate. The first based the contribution estimate solely upon adipose fin clips. Although this was the quickest of the methods, the combination of low hatchery returns and the variability about the tag-clip regression led to poor estimates. The second method was based on numbers of tags detected in heads but not extracted or decoded. While more time was required to detect actual tags, the problems associated with the tag-clip regression were overcome. The method was, however, compromised by the 1991 wild-tagging program, in which wild fish were tagged at much higher rates than hatchery fish. The third method, using extracted and decoded tags, although the slowest, was considered the only acceptable method for the 1992 harvest. The latter method required approximately three days from sampling of the commercial catch to estimation. A postseason analysis in which other estimation methods were investigated suggested that future inseason analyses be carried out using undecoded-tag data gathered from all sampled processors.

The postseason analysis revealed that out of a commercial catch of 9.42 million pink salmon, 1.66 million fish were estimated to be of wild origin. Of the hatchery component (7.77 million pink salmon), 2.39 million, 1.99 million, 1.52 million, and 1.87 million fish were estimated to originate from the A.F. Koernig, W. Noerenberg, Cannery Creek, and Solomon Gulch hatcheries, respectively.

Tag recoveries from stream surveys made in 1992 were used to complete the estimation of oiling effects upon survival rates of adult wild pink salmon, a component of the Natural Resource Damage Assessment Fish/Shellfish Study 3. No oiling effects were observed for 1992 returns.

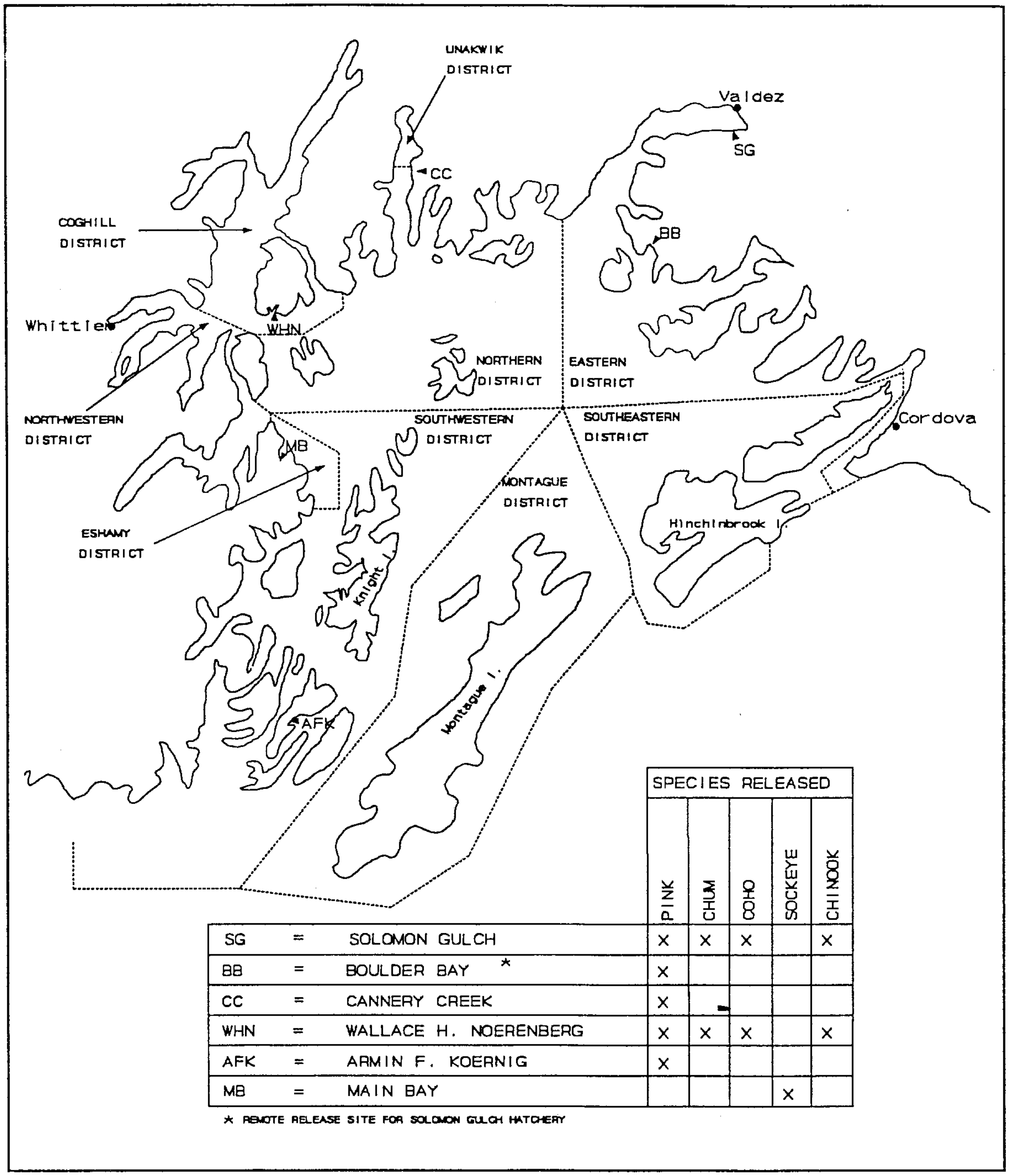
INTRODUCTION

Between 1961 and 1976, when hatcheries were absent from Prince William Sound, the commercial seine harvest of wild pink salmon *Oncorhynchus gorbuscha* averaged about 3.4 million fish. In the early 1970's, run failures led to an aggressive enhancement program which included construction of hatcheries. By 1986 five hatcheries were operating (Figure 1): the Solomon Gulch hatchery, producing pink salmon, and later, chum *O. keta*, coho *O. kisutch* and chinook salmon *O. tschawytscha*, the A. F. Koernig hatchery, producing pink salmon, the W. Noerenberg hatchery, producing pink salmon, and later, chum, coho and chinook salmon, the Cannery Creek hatchery, producing pink salmon, and the Main Bay hatchery which produced chum and presently raises sockeye salmon *O. nerka*. From the late 1980's to the present, returns to these facilities have contributed approximately 20 million fish to the annual pink salmon run. Significant numbers of sockeye, coho, chum and chinook salmon have also been produced.

Parent stocks for Prince William Sound hatchery production were selected from native populations in the Sound with the consequence that the migratory timings of adult hatchery and wild returns coincided. Furthermore, virtually all these salmon stocks migrate to their natal streams or hatcheries through corridors in the southwestern and western areas of the Sound. The coincident timing and location of the large hatchery return and the considerably smaller wild returns lead to the danger of over-exploitation of the latter by the commercial fishery. Indeed, an exploitation rate of 70% is considered appropriate for returning hatchery fish, while examination of historical data indicates shortfalls in escapements in more than half of the fifteen years prior to hatchery production when exploitation rates averaged only 42%, and did not exceed 69%. Clearly, the sustainability of the wild salmon resource of Prince William Sound must suffer if it is subjected to harvest rates appropriate for returning hatchery fish.

To protect wild stocks in a hatchery-dominated fishery, managers needed information pertaining to the temporal and spatial distributions of hatchery and wild fish. To meet this requirement, a coded wire tagging program was initiated in 1986 for hatchery releases of pink salmon with recovery of tagged returning adults in commercial and cost-recovery fisheries beginning in 1987. Tag recovery data enabled managers to estimate hatchery and wild contributions to catches from temporal and spatial strata within the fishery.

The March 24, 1989, *Exxon Valdez* oil spill (Figure 2) exacerbated the problems faced by the fishery manager. The spill contaminated intertidal portions of streams where the majority of wild salmon stocks in western Prince William Sound spawn as well as the marine waters traversed by juvenile salmon on their migration seaward through the Sound. Natural Resource Damage Assessment Fish/Shellfish (F/S) studies 2 and 4,



			SPECIES RELEASED				
			PINK	CHUM	COHO	SOCKEYE	CHINOOK
SG	=	SOLOMON GULCH	X	X	X		X
BB	=	BOULDER BAY *	X				
CC	=	CANNERY CREEK	X				
WHN	=	WALLACE H. NOERENBERG	X	X	X		X
AFK	=	ARMIN F. KOERNIG	X				
MB	=	MAIN BAY				X	

* REMOTE RELEASE SITE FOR SOLOMON GULCH HATCHERY

Figure 1. Fishing districts and hatcheries of Prince William Sound, Alaska.

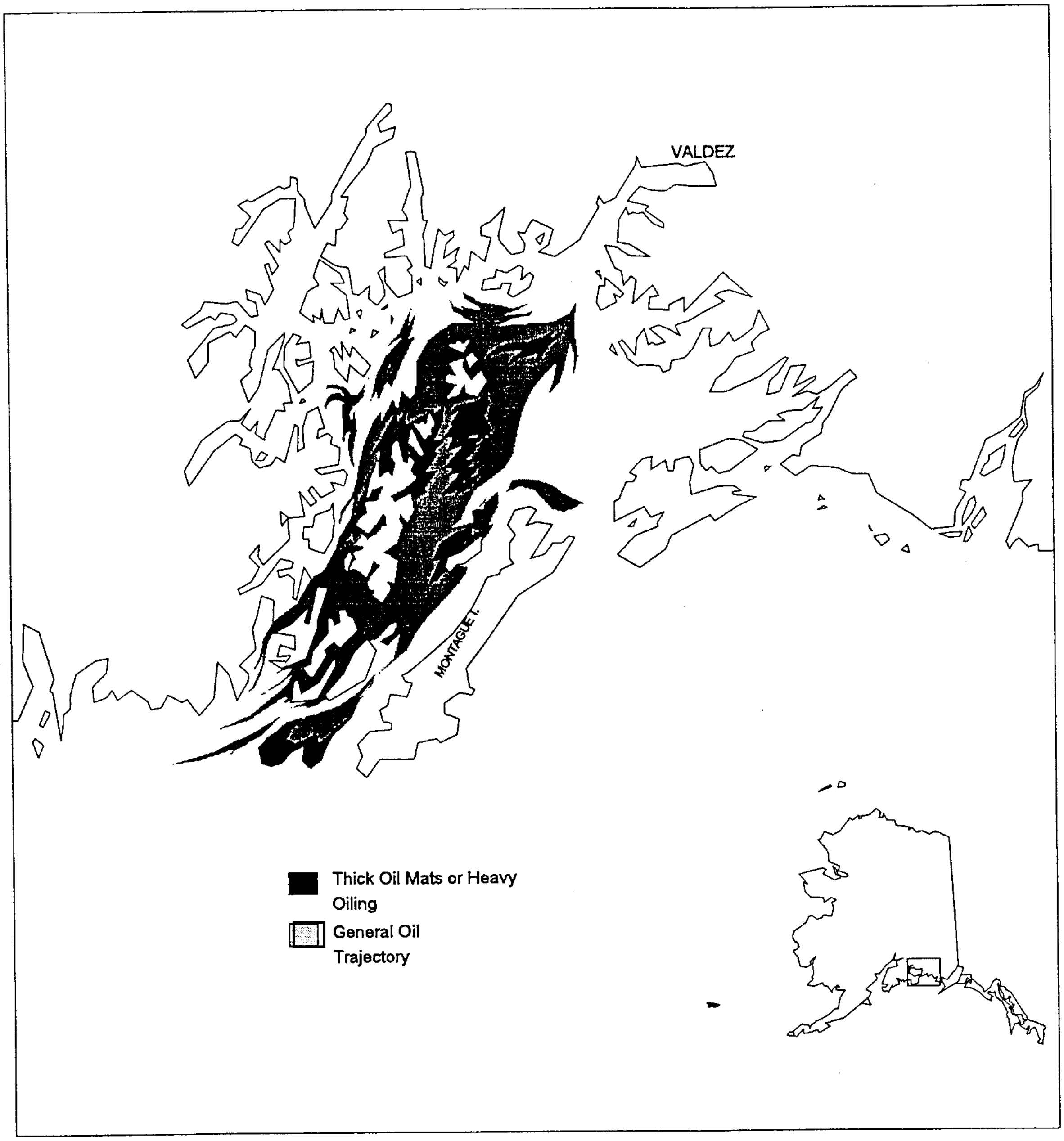


Figure 2. Trajectory of oil plume across Prince William Sound, Alaska, 1989.

demonstrated significant detrimental effects of oil contamination upon embryos, preemergent fry, and juvenile salmon from wild populations in the Sound. The decisions made by fishery managers suddenly became more critical in as far as they affected the sustainability of wild populations, as did the need for timely and accurate catch composition estimates.

The coded wire tagging program was continued through the years following the spill, and was funded under the damage assessment study F/S 3 through 1991. During this period, the program continued to provide information pertaining to the nature of the commercial salmon catch. In 1992, the pink salmon tagging program was supported through Restoration Study R60A, and while one objective of the study was to complete a component of F/S 3, namely the estimation of the oiling effect upon adult survival rates, a shift in emphasis towards the provision of timely inseason estimation of catch composition occurred. It is the activities and results of R60A that are documented in this report.

OBJECTIVES

1. To make determinations of wild and hatchery components of the pink salmon commercial fisheries of 1992 and to make these available to fishery managers on an inseason basis, so that fishing effort may be directed away from damaged wild stocks.

2. To complete the damage assessment component of Fish/Shellfish Study 3, relating to determination of survival rates of adult wild pink salmon tagged at six streams in 1991.

3. To evaluate different methods of inseason analysis of coded wire tag data.

METHODS

Tagging

Hatchery Tagging

Tagging of pink salmon fry occurred at the three Prince William Sound Aquaculture Corporation (PWSAC) facilities (W. Noerenberg, Cannery Creek, and A. F. Koernig hatcheries) and at the Valdez Fisheries Development Association (VFDA) facility (Solomon Gulch hatchery). Tagging and recovery efforts were such that contribution estimates were sufficiently precise to allow fishery managers to make meaningful in-season decisions. Assuming a sampling rate of approximately 20% of all commercial and cost recovery harvests and following an analysis of the performance of previous tagging studies (Peltz and Miller 1990; Peltz and Geiger 1990; Geiger and Sharr 1990), an overall tagging rate of approximately 0.00167 was chosen. A different tag code was given to each release group, a release group representing a batch of fish subjected to a certain feeding regimen (early feeding, late feeding or no feeding) and release timing. An effort was made to keep tagging rates as uniform as possible between hatcheries and between release groups within hatcheries.

Pink salmon fry to be tagged were randomly selected as they emerged from incubators. Fry were anesthetized in a 1 ppm solution of MS-222 prior to removal of adipose fins and application of tags. Half-length coded wire tags were applied with a Northwest Marine Technology tag injector (model MKII). Adipose fin-clipped and tagged fish were passed through an electronic quality control device to test for tag retention. Rejected fish were held and retested later. If rejected a second time, they were killed to minimize the number of untagged clipped fish in the release. Fry which retained tags were held overnight to determine short-term mortality and tag-loss. Overnight mortality rates were determined by counting the number of fish floating on the surface (floaters) 24 hours after tagging. An overnight tag loss rate was estimated by randomly selecting 200 fish and testing them with the quality control device before release into saltwater rearing pens. Tag placement was checked periodically, but not quantified.

After the overnight holding period and prior to release, all tagged fry were introduced into saltwater pens within the larger pens holding their unmarked cohorts. This allowed determination of short-term saltwater mortalities through enumeration of floaters. The number of fry released with tags of tag code t, Tr_t, was estimated for each release group by deducting both the short-term tagging and saltwater rearing mortalities from the number of fry initially tagged, and accounting for overnight tag loss :

$$\hat{Tr}_t=(T_t-Mo_t-Msw_t)(1-\hat{Lo}_t), \qquad (1)$$

where

T_t	=	total number of tagged (*t*) fish,
Mo_t	=	number of deaths during overnight holding period among tagged (*t*) fish,
Msw_t	=	number of deaths during saltwater rearing period among tagged (*t*) fish, and
Lo_t	=	proportion of tagged (*t*) fish that lost their tags during the overnight holding period.

At the PWSAC hatcheries, unmarked fry entering the large saltwater rearing pens were enumerated with electronic fry counters. At the VFDA Solomon Gulch hatchery, the numbers of unmarked fry entering saltwater net pens were estimated from egg counts, with appropriate adjustments for egg mortality. At all facilities, pink salmon fry mortalities were estimated visually immediately prior to release. These estimates were applied equally to tagged and untagged fish to obtain final release estimates. Fry and smolt releases were timed to coincide with peak plankton abundances near the hatcheri· s.

Wild Stock Tagging

Wild pink salmon fry were tagged at six streams in the western portion of Prince William Sound during 1991 (Figure 3). Three of the streams (Hayden, Herring, and Loomis Creeks) were contaminated with oil spilled from the *Exxon Valdez* and three streams were not contaminated (O'Brien, Totemoff, and Cathead Creeks). Wild fish were tagged at a considerably higher rate than hatchery fish. Tagging rates ranged from 0.1 to 0.5 and were largely functions of the rates at which field crews could work.

Wild pink salmon successfully spawn in the intertidal as well as upstream portions of streams in Prince William Sound. Successful intertidal spawning occurs in portions of stream channels more than 1.8 meters above mean low tide (Kirkwood 1962; Bailey 1966; McCurdy 1979). Total enumeration and tagging of wild pink salmon fry from streams required installation and maintenance of weirs capable of trapping fish as small as 27 mm in length in an estuarine environment with 3 m tidal fluctuations. This was accomplished by placing 3m x 3m fyke nets with nylon mesh wings at the 1.8m tide level at each stream. Each net emptied into a floating box from which fry were removed for tagging and fin clipping. Tagging at each site was temporally stratified, depending upon the magnitude and duration of the run. On each tagging day, a sample of fry was removed from the trap for tagging. Fry to be tagged were anesthetized in an MS-222 solution, had their adipose fins clipped, and were injected with a half-length coded wire tag. Recirculating freshwater systems were used to minimize osmoregulatory stress to fry

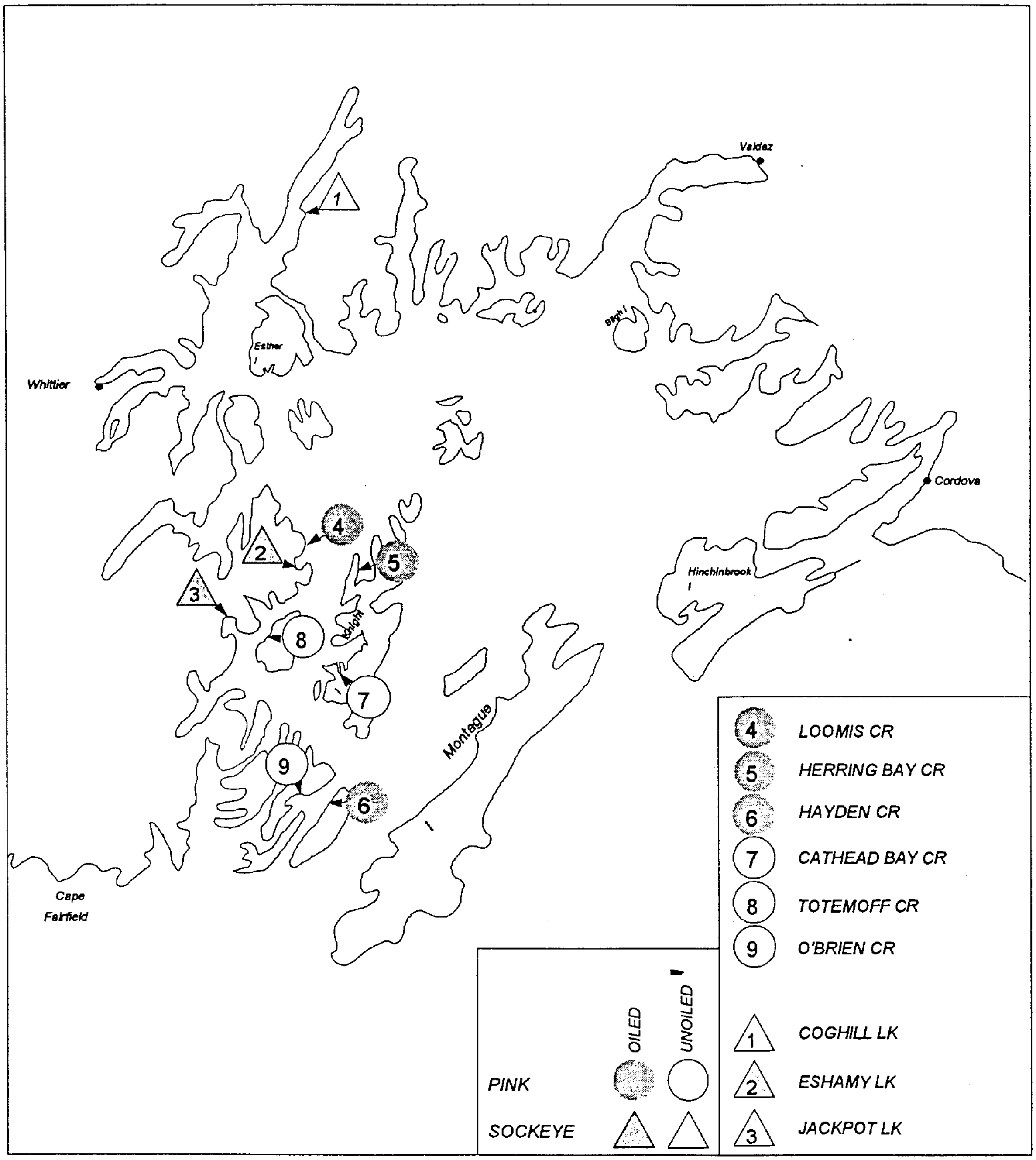


Figure 3. Pink and sockeye salmon weir sites, Prince William Sound, Alaska.

during tagging. Short-term tag loss and mortality rates were determined in a manner similar to that described for fry tagged at hatcheries. Tag placement was also checked each day. After tag retention checks, fry were introduced into saltwater net pens and held for up to 24 hours prior to release. Untagged fry were enumerated and transferred from the floating live box into the stream below the weir.

The number of wild stock fry released with tag code t (Trw_t) was estimated as:

$$\hat{Trw}_t = (T_t - Mo_t)(1 - \hat{Lo}_t), \tag{2}$$

where

T_t	=	total number of tagged (t) fish,
Mo_t	=	number of deaths during overnight holding period among tagged (t) fish, and
Lo_t	=	proportion of tagged (t) fish that lost tags during the overnight holding period.

Tag codes referred to stream identity. An upstream weir was operated at Herring Creek in conjunction with an intertidal weir in 1991, different tag codes being used at each weir to allow the origin of fish within the stream to be determined upon recovery.

Tag Recovery

Commercial and Cost-Recovery Harvests

Recoveries were stratified by district, week, and processor. This stratification was chosen as a result of the findings of Peltz and Geiger (1990) who detected significant differences between the proportions of some tag codes among such strata. The differences indicate that processors tend to receive catches from only certain parts of a district and is believed to be the result of traditional tendering patterns.

Recoveries of pink salmon tags from commercial and cost-recovery harvests were made as fish were pumped from tenders onto conveyor belts at land-based processors located in Cordova, Valdez, Seward, Anchorage, Whittier, Kenai, Kodiak and aboard floating processors after each opening. Fish were sampled by technicians standing alongside the belt. Each sampled fish was subjected to a visual and tactile examination for a missing adipose fin.

Data recorded for each tender included harvest type (i.e. commercial or cost-recovery catch), fishing district(s) from which the catch was taken, catch date, processor, the number of fish examined, and the number of adipose-fin clipped fish observed. Catch data were later obtained from fish tickets.

Heads of adipose-fin clipped fish were excised, identified with a uniquely-numbered cinch tag, bagged, frozen, and together with sample data, shipped daily to the Alaska Department of Fish and Game Coded Wire Tag Processing Laboratory in Juneau (Tag Lab). Tag Lab staff located and removed tags from heads, decoded extracted tags, and entered tag code and sample data into a database accessible to biologists in Cordova.

Brood Stock Harvests

Tag shedding from release to return and differential mortality between tagged and untagged fish can lead to discrepancies between marking rates at release and recovery. Hatchery pink salmon brood stocks were scanned for tags in order to estimate adjustment factors which could be used to account for the loss of tags from the population. Three assumptions inherent in the use of the brood stock for this purpose are a) the brood stock consists only of fish reared at the hatchery, b) the tendency for a tagged fish to lose a tag or to die is similar for all fish marked at the same hatchery, and c) there is no influence of an implanted tag on homing fidelity. If it was believed that the first of these assumptions had been violated, adjustment factors were generated from cost-recovery harvests. With respect to the second assumption, tagging practices vary little within a facility, and it is believed that the rate of tag loss and tag-induced mortality were similar for all fish tagged within a hatchery. No direct evidence exists to refute the third assumption, although some histological evidence to this end was referenced in Sharr *et al.* (1994).

The adjustment factor for hatchery h, a_h, was estimated as the ratio of sampled fish in the brood stock to the expanded number of fish based on tags found in the sample :

$$\hat{a}_h = \frac{s_h}{\sum_{i}^{T} \frac{x_i}{p_i}} , \tag{3}$$

where

T	=	number of tag codes released from hatchery h,
p_i	=	tagging rate at release for tag code i (defined as number of tagged fish released with code i divided by the total number of fish in release group i),
x_i	=	number of tags of code i found in s_h, and
s_h	=	number of brood stock fish examined in hatchery h.

The factor is 1.0 when there is no tag loss or differential mortality, and there are no violations of the closed population assumption.

The adjustment factor was used to adjust contribution estimates (Equation 4) if it could be shown that it was significantly greater than 1.0 at the 90% level. An appropriate test of the hypothesis : $Ho : a_h \leq 1.0$ is given in Sharr *et al.* (1994).

Brood stock samples were taken during hatchery egg-take operations. Technicians stationed at each of the four Prince William Sound pink salmon hatcheries examined approximately 95% of the fish through visual and tactile means for missing adipose fins. The number of fish sampled was recorded daily. When adipose-clipped fish were found, the heads were excised and shipped on a weekly basis along with sample data to the Tag Lab.

Stream Recoveries

Pink salmon carcasses were sampled for coded wire tags at all six wild stock tagging locations (Loomis, Cathead, Herring, Totemoff, O'Brien, and Hayden) in 1992, and at 18 additional streams surveyed as part of NRDA F/S 1 (Figure 3). Heads were removed from carcasses found to lack adipose fins, soaked in a brine solution, bagged, and sent to the Tag Lab along with sample data. Estimates of adjustment factors were generated in a manner similar to that for hatchery fish (Equation 3, with h indexing streams). Assumptions equivalent to those needed for valid hatchery adjustment factors are also required for derivation of meaningful stream adjustment factors.

Postseason Hatchery Contributions and Survival Rates

The contribution of release group t to the sampled common property, cost-recovery, brood stock and special harvests, and escapement, C_t , was estimated as:

$$\hat{C}_t = \sum_{i=1}^{L} x_{it} \left(\frac{N_i \, \hat{a}_{h(t)}}{s_i \, p_t} \right), \tag{4}$$

where

x_{it}	=	number of group t tags recovered in ith stratum,
N_i	=	total number of fish in ith stratum,
s_i	=	number of fish sampled from ith stratum,
p_t	=	proportion of group t tagged,
$a_{h(t)}$	=	adjustment factor associated with hatchery h, and
L	=	number of recovery strata associated with common property, cost-recovery, brood stock, special harvests and escapement in which tag code t was found.

The contribution of release group t to unsampled strata, Cu_t, was estimated from contribution rates associated with strata which were sampled from the same district-week openings as the unsampled strata:

$$\hat{Cu}_t = \sum_{i=1}^{U} \left[N_i * \left(\frac{\sum_{j=1}^{S} \hat{C}_{tj}}{\sum_{j=1}^{S} N_j} \right) \right], \tag{5}$$

where

U	=	number of unsampled strata,
N_i	=	number of fish in ith unsampled stratum
S	=	number of strata sampled in the period in which the unsampled stratum resides,
C_{tj}	=	contribution of release coded with tag t to the sampled stratum j, and
N_j	=	number of fish in jth sampled stratum.

When a district-week opening was not sampled at all (an infrequent occurrence), the catch from that opening was treated as unsampled catch of the subsequent opening in the same district.

An estimate of the contribution of tag group t to the total Prince William Sound return for 1992 was obtained through summation of contribution estimates for sampled and unsampled strata. An estimate of the total hatchery contribution to the Prince William Sound return was calculated through summation of contributions over all release groups.
A variance approximation for $\hat{C}_t$, derived by Clark and Bernard (1987) and simplified by Geiger (1990) was used:

$$\hat{V}(\hat{C}_t) = \sum_{i=1}^{L} x_{it} \left[\frac{N_i\ \hat{a}_{h(t)}}{s_i\ p_t}\right]\left[\frac{N_i\ \hat{a}_{h(t)}}{s_i\ p_t} - 1\right]. \tag{6}$$

Assuming that covariances between contributions of different release groups to a stratum could be ignored, summation of variance components over all tag codes provided an estimate of the variance of the total hatchery contribution. Inspection of the formula given by Clark and Bernard (1987) for the aforementioned covariances shows them to be negligible for large N and s, and to be consistently negative, so that when ignored, conservative estimates of variance are obtained. Variances associated with contribution estimates made for unsampled strata are believed to be small (Sharr *et al.*, 1994).

The survival rate of the release group coded with tag t (S_t), was estimated as:

$$\hat{S}_t = \frac{\hat{C}_t + \hat{Cu}_t}{R_t}, \tag{7}$$

where

C_t	=	contribution of release coded with tag t to sampled strata,
Cu_t	=	contribution of release group coded with tag t to unsampled strata, and
R_t	=	total number of fish in release group coded with tag t released from hatchery.

Assuming the total release of fish associated with a tag code is known with negligible error, and that the cumulative variance contributions associated with contribution estimation for unsampled strata are small, a suitable variance estimate for $\hat{S}_t$ is given by:

$$\hat{V}(\hat{S}_t) = \frac{\sum_{i=1}^{L} x_{it} \left[\frac{N_i\ \hat{a}_{h(t)}}{s_i\ p_t}\right]\left[\frac{N_i\ \hat{a}_{h(t)}}{s_i\ p_t} - 1\right]}{R_t^2}. \tag{8}$$

Inseason Hatchery Contributions

Inseason estimates of hatchery contributions of pink salmon were generated for openings in the Southwestern District with a variety of methods. The simplest and most timely method was based upon a historical relationship between adipose fin clips and tags in the snout (see Appendix A). A slower, but more precise method (Method 1) depended on numbers of tags (undecoded) found in heads using a magnetic detector rather than on extracted and fully decoded tags. To derive inseason estimates based upon numbers of undecoded tags, assumptions concerning expansion factors ($1/p_t$) and adjustment factors (a_h) were required (see Equation 4). For fishery openings in the Southwestern District, late-run hatchery returns from PWSAC facilities were assumed to be the only hatchery contributors and an expansion factor of 566, the average of all expansion factors associated with tags released at the A.F. Koernig (574), W. Noerenberg (544) and Cannery Creek (580) hatcheries in 1991, was used. The adjustment factor was taken as 1.63, which was the average of the historical adjustment factor estimates for the same three hatcheries (1.46, 1.61, and 1.83, respectively). Calculations of inseason contributions followed those used to generate postseason results (Equation 4). Method 3 used data from extracted and fully decoded tags, which allowed use of specific expansion factors. Use of historical adjustment factor estimates was still required, but knowledge of tag identities allowed hatchery-specific historical factors to be used. Other methods (Methods 2 and 4) of inseason estimation which were expected to show promise for future years were examined using postseason (Method 5) knowledge of tag codes.

Wild Salmon Contributions and Survival Rates

Contribution and survival estimates for tagged wild salmon were derived in a manner similar to those for tagged hatchery fish (Equations 4, 5 and 7), as were the estimates of variances of the contribution and survival rates (Equations 6 and 8). An estimate of the contribution of the release group coded with wild stock tag t to the total Prince William Sound return was obtained from the summation of estimates of contributions to the common property and cost-recovery harvests and of the estimates of the returns to all surveyed streams.

Analysis of variance was used to determine the effect of oil upon survival rates of wild pink salmon. The analysis reflected the completely randomized nature of the design. Survival rates (Y_{ij}) were modelled with the effects model as:

$$Y_{ij} = \mu + oil_i + \epsilon_{ij} , \tag{9}$$

where

i = 1 or 2 for oiled and unoiled, respectively, and

j = 1, 2 or 3 for streams within oiled areas.

RESULTS

Tagging

Hatchery Tagging

Pink salmon fry were released from the A.F. Koernig, W. Noerenberg, Cannery Creek, and Solomon Gulch hatcheries in 1992 (Table 1). Pink salmon were by far the most abundant salmon species cultivated and released from Prince William Sound hatcheries. Numbers of pink salmon fry released ranged from 86 million for the Solomon Gulch hatchery to 163 million for the W. Noerenberg hatchery. Tagging rates among facilities were fairly constant and in the region of 0.00182. Solomon Gulch applied 4 tag codes, while the remaining hatcheries applied 14 or 16 codes.

Wild Stock Tagging

Numbers of pink salmon fry migrating seaward from the six wild stock study streams in 1991 ranged from 152 thousand to 510 thousand, with a median of 306 thousand. Tagging rates ranged from 0.098 to 0.667 with a median of 0.2 (Table 2).

Tag Recoveries

Sampling Rates

Approximately 23% of the pink salmon captured in the common property and 31% of those captured in the cost-recovery harvests were sampled during 1992. These sampling rates were functions of the magnitudes of the catch, the number of samplers and the short time period the fish were accessible to the samplers. The proportion of the pink salmon brood stock sampled was 93%. Approximately 90% of the pink salmon carcasses found in survey streams were scanned for tags.

Hatchery Tag Recoveries

Postseason contributions and survival rates. Tags from hatchery produced pink salmon were recovered in the common property, cost-recovery and brood stock harvests. Some hatchery tags were also recovered during surveys of pink salmon spawning streams. Hatcheries contributed 7.76 million pink salmon (82%) to the total Prince William Sound catch of 9.42 million (Table 3). The A.F. Koernig hatchery was the largest producer among the four hatcheries cultivating pink salmon in the Sound,

Table 1. Hatchery tagging data for pink salmon by facility for 1992, Prince William Sound, Alaska.

	NUMBER			TAGGING RATE
	RELEASED	TAG CODES	TAGGED	
A.F. Koernig	112,830,588	16	202,421	0.00179
W. Noerenberg	163,802,656	14	299,241	0.00183
Cannery Creek	132,166,231	14	233,505	0.00177
Solomon Gulch	86,902,415	4	160,733	0.00185

Table 2. Wild pink salmon tagging data for 1991, by stream and tag code, Prince William Sound, Alaska.

SYSTEM	DATE OF RELEASE	SEAWARD MIGRATION	TAG CODE	NUMBER TAGGED	TAGGING RATE
HAYDEN	4/19 - 6/20	388,739	1301011407 1301011408 1301011409	61,683	0.159
HERRING	4/26 - 6/27	261,751	1301011313 1301011315 1301011515 1301011312	57,953	0.222
	6/02 - 6/27[a]	11,457	1301011311	7,614	0.667
LOOMIS	4/18 - 6/20	152,446	1301011401 1301011402 1301011403 1301011514	60,393	0.400
CATHEAD	4/23 - 6/09	234,998	1301011404 1301011405 1301011406	36,376	0.154
O'BRIEN	4/13 - 7/08	347,576	1301011410 1301011411 1301011412 1301011314	63,077	0.182
TOTEMOFF	4/19 - 5/27	510,213	1301011309 1301011310 1301011308	49,817	0.098

a Denotes upstream tagging

Table 3. Summary of hatchery and wild stock contributions to the Prince William Sound pink salmon catch of 1992 (millions of fish).

CONTRIBUTOR	FACILITY[a]	COMMON PROPERTY	COST RECOVERY	BROOD STOCK	TOTAL CONTRIBUTION	95% BOUNDS	% OF TOTAL CATCH
Hatchery	AFK	1.60	0.64	0.15	2.39	(2.2,2.5)	25.37
	WN	1.32	0.44	0.23	1.99	(1.9,2.1)	21.13
	CC	1.04	0.31	0.17	1.52	(1.4,1.7)	16.14
	SG	0.38	1.24	0.24	1.86	(1.6,2.1)	19.75
	TOTAL	4.34	2.63	0.79	7.76	(7.4,8.1)	82.39
Wild stock		1.23	0.43	0.00	1.66	(1.3,2.0)	17.61

a AFK = A.F. Koernig, WN = W.Noerenberg, CC = Cannery Creek, SG = Solomon Gulch contributing 2.39 million fish (25%). Survival rates (over all tag codes) of adult hatchery pink salmon were 2.08% for A.F. Koernig, 0.94% for W. Noerenberg, 1.08% for Cannery Creek, and 1.43% for Solomon Gulch (Table 4). No significant difference (at α=0.05) was detected between the survival rates of pink salmon released from the W. Noerenberg and Cannery Creek hatcheries (P=0.08). The survival rate of pink salmon released from the Solomon Gulch hatchery was significantly different from the rates associated with the W. Noerenberg and Cannery Creek hatcheries (P<0.0005). The survival rate of fish released from the A.F. Koernig hatchery was different from that of all other hatcheries (P<0.0001). The above tests assume zero-covariance between the survival rates tested within each comparison and that the variability associated with unsampled strata is minimal.

Adjustment factors. Adjustment factors for the A.F. Koernig and W. Noerenberg facilities were estimated from pink salmon brood stocks, while those for the Cannery Creek and Solomon Gulch hatcheries were based upon cost-recovery sampling due to fears of contamination of the brood stock at these facilities by nearby wild spawning populations (Table 5). The adjustment factors generated from the brood stocks at the latter facilities were 2.74 , and 2.55 respectively. All adjustment factor estimates were found to be significantly greater than 1.0 (P <0.1).

Inseason pink salmon contributions. The only acceptable method used on a real-time basis in 1992 was based upon decoded tags (Table 6, Figure 4, Method 3). Estimates based upon a relationship between numbers of fish found with clipped adipose fins and fish found with tags (see Appendix A) were found to agree poorly with those generated from a postseason treatment of the data. Inseason estimates of hatchery contributions based only upon knowledge of the presence or absence of tags (Method 1) also agreed poorly with postseason estimates (Table 6, Figure 4, Method 1 vs. Method 5). Other methods which were believed to hold promise for the future were examined using postseason information. One of these, Method 2, involved modification of Method 1 (undecoded tag method) through use of postseason information to discount wild tags. Agreement between Methods 2 and the postseason analysis was good (Table 6, Figure 4, Method 2 versus Method 5). Method 2 included only data from a subset of sampled catches and the accuracy of that method further improved when data from all processors were included (Table 6, Figure 4, Method 4 versus Method 5).

Wild Pink Salmon Tag Recoveries

Contributions and survival rates. Wild pink salmon tag recoveries were made in the common property and cost-recovery harvests and in the surveyed streams (Table 7).
The estimated contribution of wild pink salmon to the Prince William Sound pink salmon harvest was 1.66 million fish (17.6%) (Table 3). As hatchery produced pink salmon were found in wild salmon spawning streams, some tagged wild fish were observed in hatchery brood stock harvests (one Hayden Creek tag in brood stock at the

Table 4. Survival rates of pink salmon returning to Prince William Sound hatcheries in 1992.

FACILITY	SURVIVAL RATE (%)	95 % BOUNDS
A.F. Koernig	2.08	(1.96,2.19)
W. Noerenberg	0.94	(0.88,0.99)
Cannery Creek	1.08	(0.98,1.19)
Solomon Gulch	1.43	(1.30,1.56)

Table 5. Adjustment factors, standard errors and P values from brood stock or cost recovery harvests for 1992.

FACILITY	ADJUSTMENT FACTOR	STANDARD ERROR (ADJUSTMENT FACTOR)	P VALUE FOR Ho:A.Factor <=1.0
A. F. Koernig	1.43	0.1026	0
W. Noerenberg	1.63	0.1079	0
Cannery Creek*	1.58	0.2035	0.0021
Solomon Gulch*	1.25	0.0453	0

* Adjustment factors and standard errors calculated from cost-recovery harvests.

Table 6. Estimates of hatchery contributions (percent of catch) for openings in the Southwestern District of Prince William Sound in 1992 as determined by five different methods.

METHOD	PERIOD					
	7/27	7/30	8/03	8/05	8/08	8/11
Undecoded, plus wild tags (1)*	85	88	78	93	96	81
Undecoded, no wild tags (2)	79	73	62	90	84	78
Decoded, no wild tags (3)*	78	70	58	89	82	76
Undecoded, no wild tags, all processors (4)	75	60	71	91	87	82
Full Postseason analysis (5)	69	56	68	87	84	77

Method 1 Undecoded tags, including wild tags, using an expansion factor of 566 (average of tags released from A.F.Koernig, W.Noerenberg, and Cannery Creek) and an adjustment factor of 1.63 (average of historical adjustment factor estimates for A.K. Koernig, W.Noerenberg and Cannery Creek hatcheries).

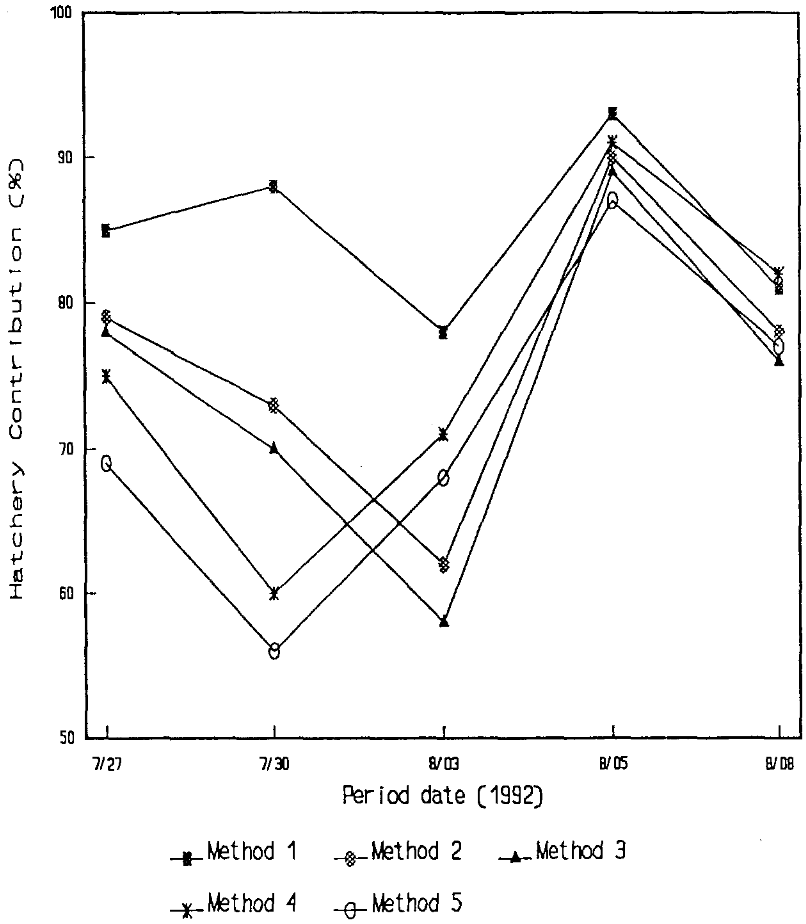
Method 2 Undecoded tags, excluding wild tags, using factors as in Method 1.

Method 3 Decoded tags, excluding wild tags, using code-specific expansion factors and hatchery-specific estimates of historical adjustment factors.

Method 4 Undecoded tags, excluding wild tags, using factors as in Methods 1, and using data from all sampled processors.

Method 5 Full postseason analysis, excluding wild tags, using code-specific expansion factors and hatchery-specific 1992 estimated adjustment factors.

* Denotes that the method was used to generate inseason hatchery contribution estimates in 1992.



Method 1	Undecoded tags, including wild tags, using an expansion factor of 566 (average of tags released from A.F.Koernig, W.Noerenberg, and Cannery Creek) and an adjustment factor of 1.63 (average of historical estimated adjustment factors for A.K. Koernig, W.Noerenberg and Cannery Creek hatcheries).
Method 2	Undecoded tags, excluding wild tags, using factors as in Method 1.
Method 3	Decoded tags, excluding wild tags, using code-specific expansion factors and hatchery-specific historical estimated adjustment factors.
Method 4	Undecoded tags, excluding wild tags, using factors as in Methods 1, and using data from all sampled processors.
Method 5	Full postseason analysis, excluding wild tags, using code-specific expansion factors and hatchery-specific 1992 estimated adjustment factors.

Figure 4. Estimates of hatchery contributions (percent of catch) for openings in the Southwestern District of Prince William Sound in 1992, as determined by five different methods.

Table 7. Tags recovered in pink salmon wild stock streams in Prince William Sound by hatchery or stream of origin in 1992.

RECOVERY STREAM[c]	TAG ORIGIN										
	WILD STOCK STREAM						HATCHERY[a]				TOTAL TAGS[b]
	CATHEAD	HAYDEN	HERRING	LOOMIS	O'BRIEN	TOTEMOFF	AFK	CCH	WN	SGH	
225-30-15060 (LOOMIS)	0	0	3	13	0	0	0	0	3	0	6
226-10-16940 (HERRING)	0	0	8	0	0	0	0	0	0	0	0
226-20-16210 (TOTEMOFF)	0	0	1	0	0	132	0	0	0	0	1
226-20-16990 (CATHEAD)	6	0	0	0	0	0	0	0	0	0	0
226-40-16660 226-40-16665 (O'BRIEN[d])	0	0	0	0	1	0	1	0	2	0	3
226-40-16770 226-40-16768 (HAYDEN[d])	0	4	0	0	0	0	1	0	0	0	1
221-40-10760	1	0	0	0	0	2	0	3	1	5	12
221-60-11368	0	0	0	0	0	0	0	0	0	1	1
221-60-11425	0	0	0	0	0	0	0	0	0	3	3
221-60-11450	0	0	0	0	0	0	0	0	0	1	1
224-30-14760	0	0	0	0	0	0	0	0	1	0	1
224-40-14800	0	0	0	0	0	1	0	0	0	0	1
225-20-15050	0	0	0	1	0	0	0	0	1	0	2
225-30-15070	0	0	1	1	0	0	0	0	0	0	2
225-30-15080	0	0	1	1	0	0	1	0	0	0	3
225-30-15100	0	0	1	0	0	0	1	0	0	0	2
225-30-15110	0	0	0	0	0	0	1	0	3	0	4
226-20-16020	0	0	0	0	0	1	0	0	0	0	1
226-20-16040	0	0	0	0	0	5	0	0	0	0	5
226-20-16230	0	0	0	0	0	0	0	1	0	0	1
226-20-16280	0	1	1	2	0	2	4	0	1	0	11
226-20-16360	0	0	0	0	0	0	1	0	1	0	2
226-20-16949	0	0	0	0	0	1	0	0	1	0	2
226-40-16610	0	0	0	0	0	0	1	0	0	0	1
226-40-16650	0	0	0	0	0	0	3	0	0	0	3
TOTAL TAGS[b]	1	1	8	5	0	12	14	4	14	10	69

a AFK = A.F. Koernig, WN = W.Noerenberg, CC = Cannery Creek, SG = Solomon Gulch.
b Excluding tags from the stream of origin.
c From Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes, 1990.
d Recovery area covers two stream systems.

Cannery Creek hatchery, and one Totemoff Creek tag in brood stock at the at W. Noerenberg facility).

No significant difference in survival rates of pink salmon returning to oiled and unoiled streams was found in 1992 (P=0.65). Mean survival rates (from tagging to adults) were 0.24% for oiled and 0.36% for unoiled streams (Table 8).

Adjustment factors. Estimated adjustment factors for the tagged wild stocks were found to be high, *i.e.* values of 52, 18, 7, 102, 216, and 74 were calculated for Loomis, Herring, Totemoff, Cathead, O'Brien, and Hayden Creeks respectively (account was taken of estimated numbers of hatchery fish in the streams, as indicated by the presence of hatchery tags). The generated estimates were not used and a_h was set to 1.0 in Equations 4, 6, and 8.

Table 8. Survival rates of wild pink salmon returning in 1992.

OILING STATUS	STREAM OF ORIGIN	SURVIVAL RATE (%)	95% C.I. (LOWER, UPPER)
OILED			
	Hayden	0.07	(0.044, 0.096)
	Herring	0.47	(0.399, 0.581)
	Herring[a]	0.00	
	Loomis	0.19	(0.152, 0.226)
UNOILED			
	O'Brien	0.02	(0.003, 0.036)
	Totemoff	0.70	(0.592, 0.806)
	Cathead	0.35	(0.229, 0.459)

a Denotes upstream tagging

DISCUSSION

Contributions of Hatchery and Wild Fish to the Commercial Catch

The coded wire tagging program was successful in providing precise postseason estimates of contributions of hatchery-reared salmon to commercial catches (Tables 3, 5). While it appears that tagging and sampling rates were adequate, the accuracy of the estimates depends upon whether certain assumptions, listed below and discussed at length in Sharr *et al.* (1994), were met.

1. The tagging rate is known exactly.
2. The number of fish in the fishery (or each recovery stratum) and the number of fish in the fishery sample are known exactly.
3. The tagged sample is a simple random sample (i.e. every fish in the collection of fish has an equal probability of selection independent of every other fish in the sample).
4. All marks in a sample are observed and all tags decoded.
5. The sample of the fishery is a simple random sample.
6. The use of adjustment factors is valid.

Most assumptions appear to have been met in the present study, although there is some uncertainty as to the validity of assumption 6 (see below).

A major emphasis during the 1992 pink salmon fishery was to provide fishery managers with real-time, inseason estimates of hatchery contributions, specifically for the openings occurring in the Southwestern (226) District. It was hypothesized that the quickest contribution estimates could be made by estimating numbers of returning tags from adipose-clip data obtained from samples taken at the processors in Valdez and Cordova. Indeed, a highly significant regression of tags on adipose fin clips was obtained from historical data (Appendix A). Unfortunately, through comparisons of contribution estimates made by this method to those made from actual tag data, it soon became apparent that the method was inappropriate. While much of the variation in historical tag occurrences was explained by clip counts, relatively few hatchery fish returned in 1992. This resulted in predictions being made at the lower end of the range of data used to fit the regression equation. Since the half-widths of prediction intervals were similar to the number of predicted tags, the method was of little practical use.

Problems with the imprecision of the tag versus adipose fin-clip regression were overcome by waiting for the Tag Lab to determine the actual number of tags in the samples of heads taken from the processors and basing contribution estimates upon numbers of (undecoded) tags (Method 1). Method 1 performed poorly due to the presence of wild tags, wild fish having been tagged at a much higher rate than hatchery stocks in 1991. Without decoding, wild tags were counted as hatchery tags and inflated the calculated proportion of hatchery fish. Method 2, in which wild tags were accounted for, yielded results closer to those of the postseason analysis. Method 3, based on full decoding along with use of tag-specific expansion factors and hatchery-specific historical adjustment factor estimates, provided estimates similar to Method 2. The major difference between estimates based on either Methods 2 or 3 and the postseason analysis arose from the large catch landed at the Icicle processor in Seward during the 30 July period which was not included in the inseason analyses. This catch consisted predominantly (80%) of wild pink salmon. Method 4, in which undecoded tag data (excluding wild tags) from all sampled processors were used, appears to be the most promising inseason analysis. With the wild tagging program having been terminated in 1991, meaningful inseason contribution estimates could probably be obtained very quickly in the future. To accomplish this, scanners capable of detecting tags in excised heads should be deployed at all sampled processors, with tag data being immediately transmitted to biologists in Cordova. Inseason estimates of contribution rates could then be made available to fishery managers within 24-48 hours of the termination of the fishing period.

Inseason management of the pink salmon fishery was influenced by results of the coded wire tagging program. For example, the decision to confine the commercial fleet to the terminal areas of the hatcheries about half way through the season was partly based on coded wire tag data. Another example is that of the movement of the southern boundary of the Unakwik district after tag data suggested large numbers of wild fish were being taken in the commercial harvests in that area. Coded wire tag data were also used to determine the size of the hatchery return, so that an appropriate cost-recovery harvest could be determined (the hatcheries are permitted to recover 30% of their return to cover expenses).

Survival Rates of Hatchery Fish

Survival rates of hatchery reared pink salmon were considerably lower than those found in previous years. In 1991, survival rates were estimated to range from 4 to 6 % (Sharr *et al.*, 1994), while in 1992, the highest rate was 2%. The data of Willette and Carpenter (1994) leads to the hypothesis that low ocean temperatures led to reduced juvenile growth rates in 1991, which led to depressed survival rates of returning adults.

Survival Rates of Tagged Wild Fish

There was very little evidence of an oiling effect on survival rates of adult pink salmon returning to the six study streams in southwestern Prince William Sound in 1992. It should be noted, however, that the small size of the experiment (three replicates) in conjunction with the inherently large variability of natural systems precluded detection of all but near-catastrophic effects of oiling on survival rates. It is estimated that in order to detect a difference in survival rates between oiled and unoiled streams, the populations from the former would have had to have been almost wiped out. Another problem with the analysis pertains to the generation of unreasonably high estimates of adjustment factors for the streams in question. Rather than use these estimates, it was decided to set the adjustment factors to

1.0 for all streams. The calculated survival rates are therefore underestimated. It is not thought that this action compromises treatment comparisons, however, since the underestimation is likely to be similar for all treatments (tagging methods were similar at all streams). The lack of randomization of 'treatment' applications (i.e. oiled and unoiled) to experimental units (i.e. streams) should also be borne in mind when considering the results. Since streams which became oiled tended to lie on the eastern side of islands in the southwestern part of Prince William Sound, any oiling effect became confounded with geological and environmental factors. No prespill comparisons of survival rates of pink salmon originating from streams on the eastern versus western sides of the islands are available.

Adjustment Factors

Consistent with the findings of Sharr *et al.* (1994), the estimated adjustment factors for the tagged wild stocks were large, with values ranging from 7 to 216. Some possible explanations, also referenced in Sharr *et al.* (1994), are presented to account for the size and variability of the estimates.

If the adjustment factors are indeed a reflection of tag shedding and/or differential mortality, then they should be used as determined. It is for such events that the adjustment factor was developed. It is possible that unusually cool ocean conditions during fry outmigration in 1992 contributed to an enhanced differential mortalitiy of tagged fish, and hence larger adjustment factors. The fact that adjustment factors calculated from hatchery brood stocks in 1992 did not exceed 2.75 argues against this explanation, however, since any temperature-mediated effect on outmigrating fry should have been of a similar magnitude for hatchery and wild fry. This argument also applies to tag shedding, and it is therefore difficult to implicate either excessive tag shedding or differential mortality in the large adjustment factors observed in the wild tagging program. Some alternative explanations are offered below.

One possibility is that the third assumption outlined in the Methods section, namely that there is no influence of the tag on homing ability, has been violated. It is hypothesized that a poorly located tag causes straying so that variability in the skill of tagging crews may contribute to the variability found in adjustment factors over streams. Morrison and Zajac (1987) found that implantation of half-length coded wire tags into the snouts of chum salmon (1500 fish/kg) resulted in visible damage to olfactory nerves in 18 of 44 fish studied. Work is under way to assess the correlation between tag placement and straying through X-ray analysis of heads from fish known to have strayed and from those known not to have strayed. As pointed out in Sharr *et al.* (1994), however, tag-induced straying might be expected to be similar for fish tagged at streams to those tagged at hatcheries. The fact that adjustment factors estimated from streams and hatchery brood stocks are an order of magnitude apart argues against the above hypothesis.

Another possibility is that significant numbers of nonnative wild fish strayed into the streams (note that the stream estimates were adjusted for the presence of hatchery fish, indicated by the presence of hatchery tags). Examination of Table 7 reveals that at approximately half of the surveyed streams nonnative tagged wild fish were found. While the adjustment factors calculated from the Solomon Gulch and Cannery Creek brood stocks were significantly smaller than those derived for the streams, they were, nevertheless suspiciously large, and it is hypothesised that the spawning population of wild fish in the outlet streams at these facilities is responsible. This eventuality was preconceived and adjustment factors for these facilities were calculated from cost-recovery harvests, in which it was rationalized that wild stocks would be more dispersed. When brood stock adjustment factors were calculated for these facilities they were indeed almost double those calculated from the cost-recovery harvests. This lends justification to the practice of using cost-recovery fish for calculation of adjustment factors at these facilities. Fluctuations in the productivity of such wild stocks could explain the variability in the adjustment factor estimates made from the brood stocks of Cannery Creek and Solomon Gulch over the years 1989 through 1992 (ranging from 1.96 to 2.74 and from 1.13 to 2.55, respectively).

Finally, problems with fry enumeration techniques could result in unexpected adjustment factor estimates. This potentially applies to the Solomon Gulch facility, where outmigrating fry were estimated from egg counts.

While not quantifying it, adjustment factor estimation has led to the realization that a certain amount of straying is probably occurring among populations of wild pink salmon in Prince William Sound. There is also evidence that hatchery fish are straying into wild spawning grounds. From an expansion of hatchery tags found in Loomis Creek it is estimated that the escapement consisted of approximately 40% hatchery fish. Analysis of 1991 wild tag recoveries reveals similar findings (D.G. Sharp, Alaska Department of Fish and Game, Cordova, personal communication). If straying is occurring to the extent that is suggested here, the implementation of policies aimed at preserving unique collections of genetic material will have to be seriously reevaluated.

CONCLUSIONS

The major objective of this study was to provide fishery managers with time and location-specific data relating to the occurrence of wild stocks in the commercial fishery, and to do this in real-time. The coded wire tagging program was shown to be capable of delivering such information within three days of an opening. The timely use of this data allowed for adjustments to fishing areas and times during the 1992 harvest. Moreover, analysis of postseason data identified new inseason methods which should provide estimates of hatchery contributions to fishery managers even more quickly.

Reasonably precise estimates of survival rates of wild pink salmon were obtained; although confounding environmental factors made it difficult to draw a strong conclusion about oiling effects. Precise estimates of hatchery survival rates were also obtained.

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APPENDIX A

The Tag/Clipped-Adipose-Fin Regression Model.

Objective

A relationship between the number of adipose clips found in a sample of pink salmon from a harvest-district-week-processor stratum and the number of coded wire tags found in the same sample was sought.

Model Development

Data. Data from returns of Prince William Sound Aquaculture Corporation pink salmon over three seasons were used to estimate the relationship. Some preliminary analysis demonstrated the relationship to differ little among years, between origin of the catch (common property, private nonprofit), and among periods of the fishery. The relationship to be estimated was thus one between tags and adipose clips.

Model. A plot of the data is given in Figure A1. The relationship between tags (Tags) and clips (Clips) appears to be linear and to pass through the origin. The variance of the errors (from a linear model) also appear to be strongly dependent upon the mean, suggesting a multipicative error structure. The model described in Equation A1 was considered potentially suitable:

$$Tags_i = \beta \; Clips_i(1 + \epsilon_i^*) \;, \qquad \text{(A1)}$$

such that $E(\epsilon_i^*)=0$, and $V(\epsilon_i^*)=c$, with $E(Tags_i)=\beta \; Clips_i$ and $V(Tags_i)=E(Tags_i)^2c$.

Taking Logs of both sides of Equation A1 yields:

$$Log(Tags_i) = Log \; \beta + Log \; (Clips_i) + Log(1+\epsilon_i^* \;), \qquad \text{(A2)}$$

where, $Log(1+\epsilon_i^*)$ is assumed ~N(0,k). A plot of the transformed data revealed, however, that the log transformation was somewhat of an over correction with respect to the heterogeneous variance problem (Figure A2).

To identify a more appropriate transformation of the data, the procedure developed by Box and Cox (described in Draper and Smith (1981)) was used. The transformation $(Tags^{\lambda}-1)/\lambda$ for $\lambda \neq 0$ and $\ln(Tags)=0$ for $\lambda=0$ was used where λ was identified as that value leading to maximization of the likelihood function based on the normality of $(Tags^{\lambda}-1)/\lambda$. The procedure yielded a λ of 0.8. This transformation also appeared unsatisfactory (Figure A3). Eventually, a square-root operation was found to stabilize the variance (Figure A4). The following model was chosen and fitted:

$$Tags^{0.5} = \beta * Clips^{0.5} + \epsilon_i \qquad \text{(A3)}$$

where $\epsilon_i \sim N(0,\sigma^2)$.

Fitting. Least squares yielded the following fitted model:

$$\hat{Tags}_i^{0.5} = 0.797\ Clips_i^{0.5} \qquad \text{(A4)}$$

The fitted line and 95% prediction intervals are depicted in Figure A4.

Model Diagnostics

A residual plot and the Durbin Watson test were used to examine the assumptions of normality and homogeneity of variance of error terms ($\epsilon_i \sim N(0,\sigma^2)$) (Figure A5). No evidence was found to suggest the distributional assumptions had been violated.

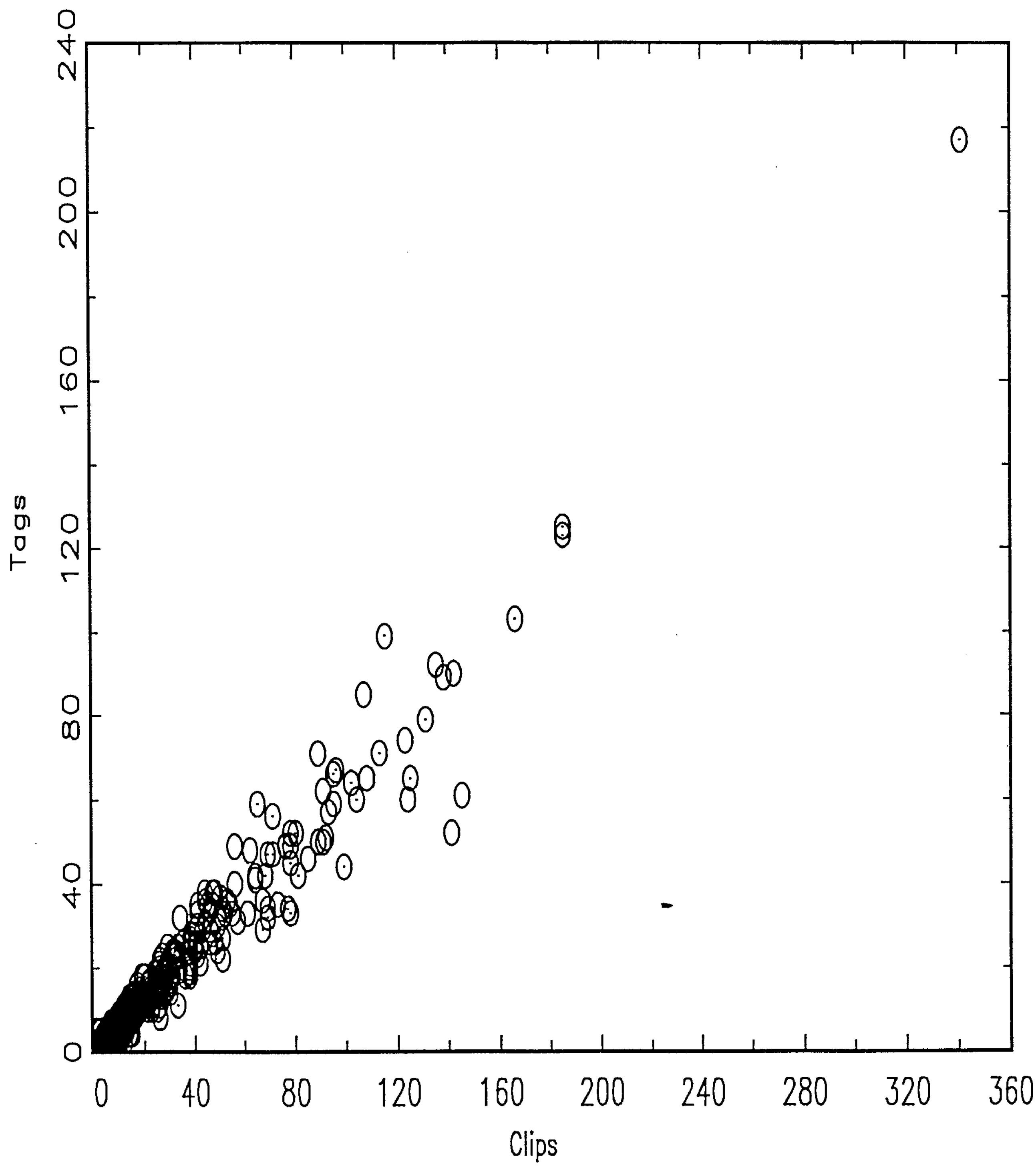

Figure A1. Plot of tags vs. adipose fin clips; each point arises from a harvest-district-week-processor stratum.

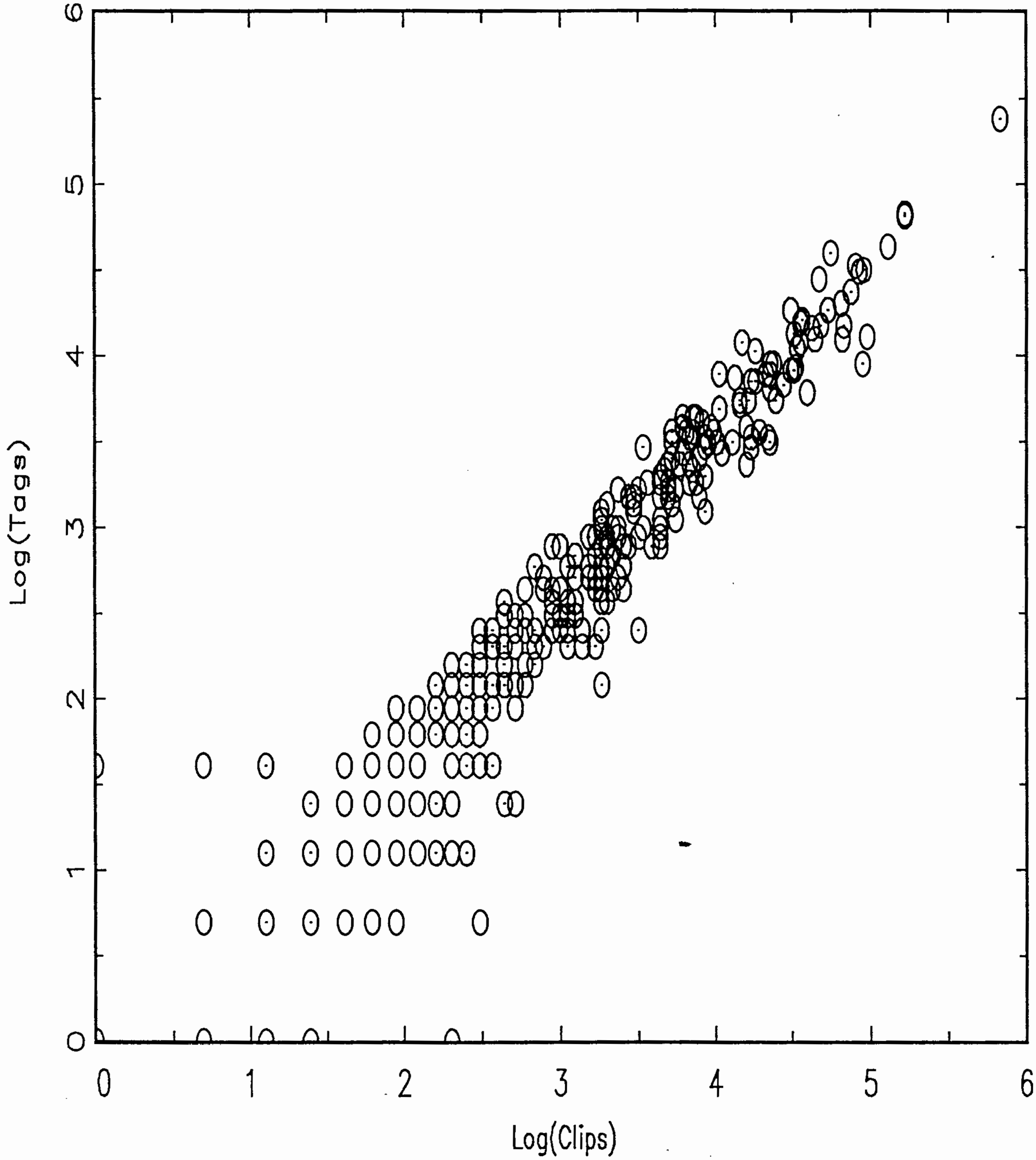

Figure A2. Plot of log-transformed data.

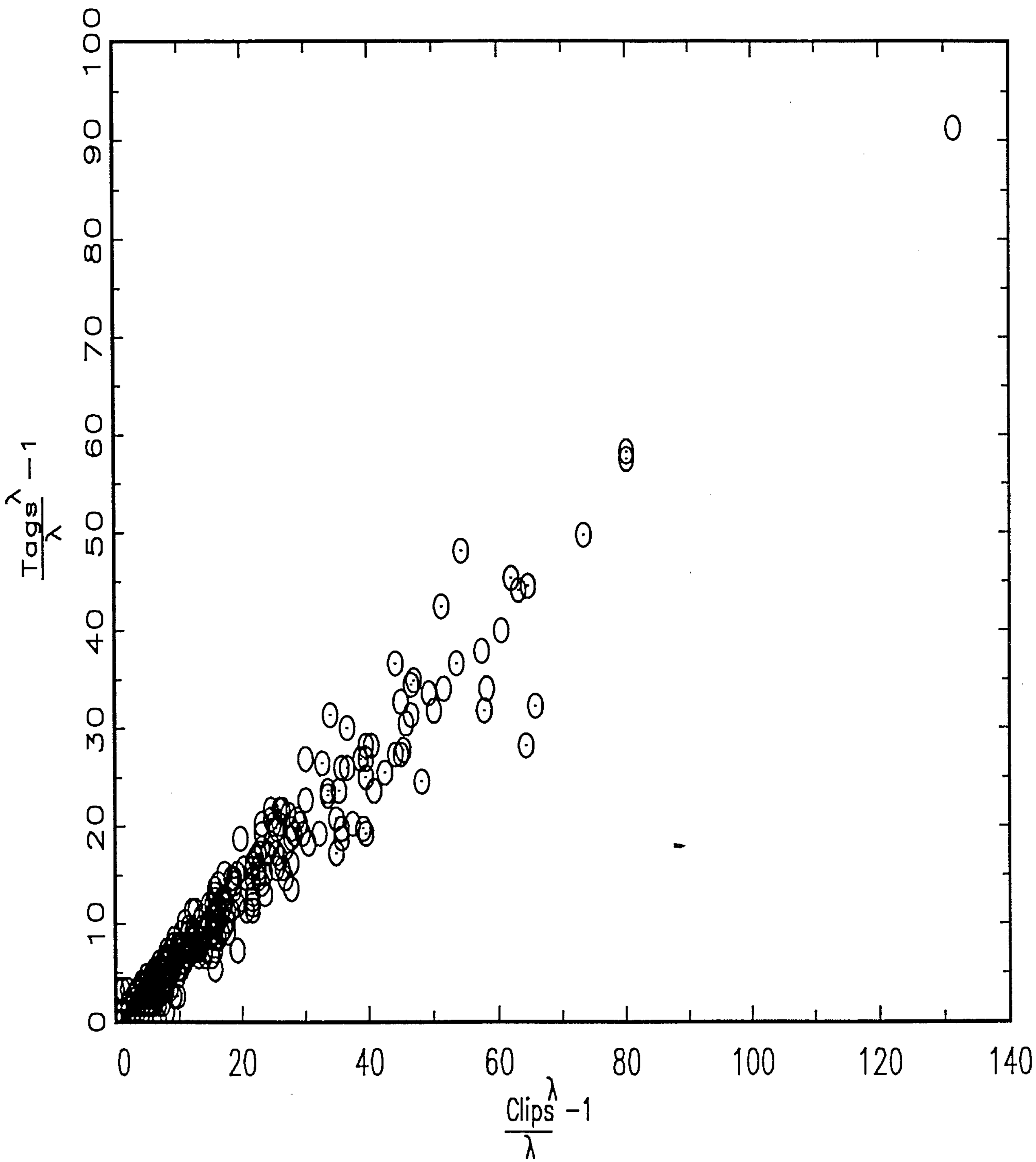

Figure A3. Plot of data after Box-Cox transformation (λ=0.8).

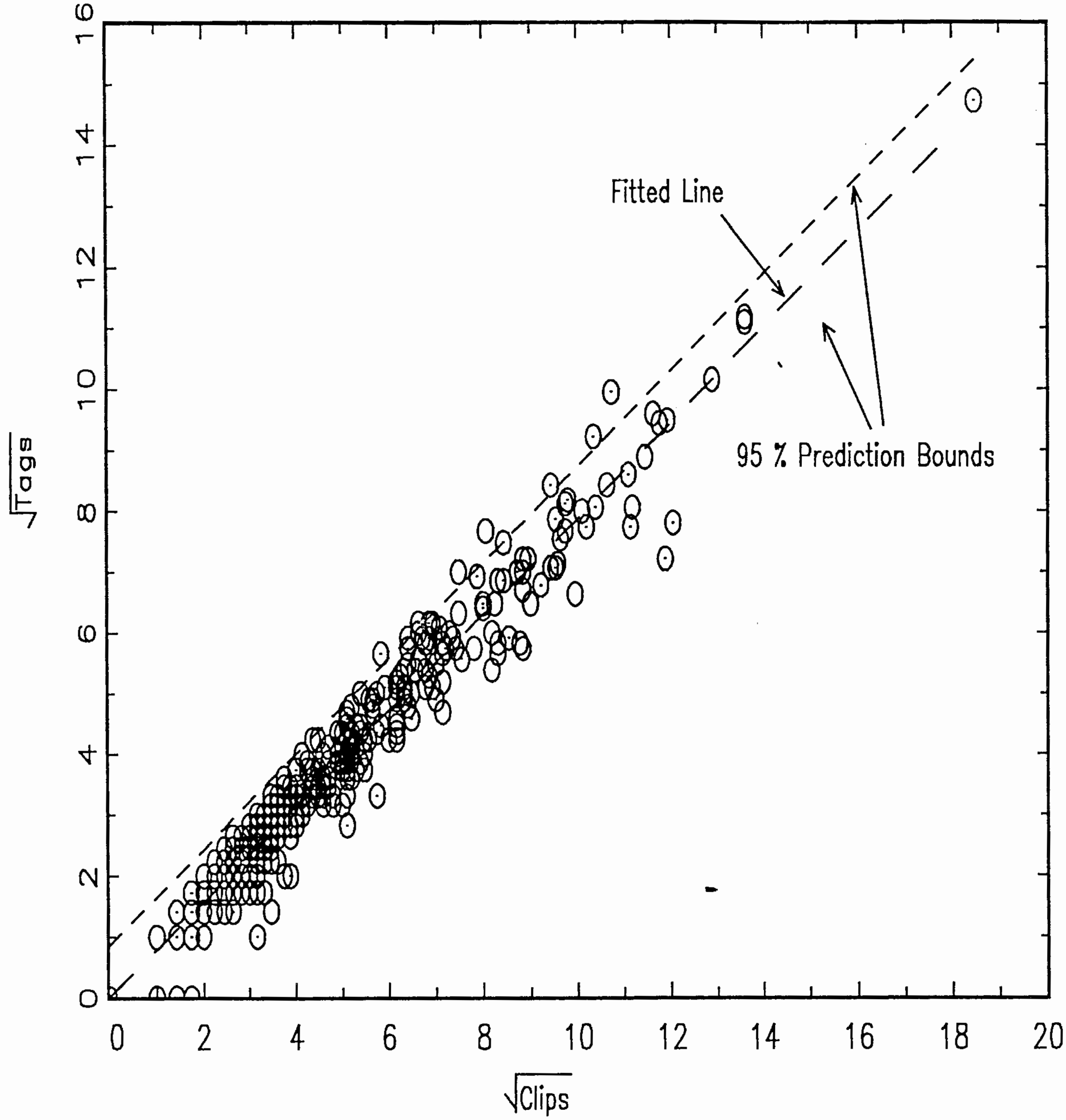

Figure A4. Plot of square-root transformed data with fitted line and 95% prediction intervals.

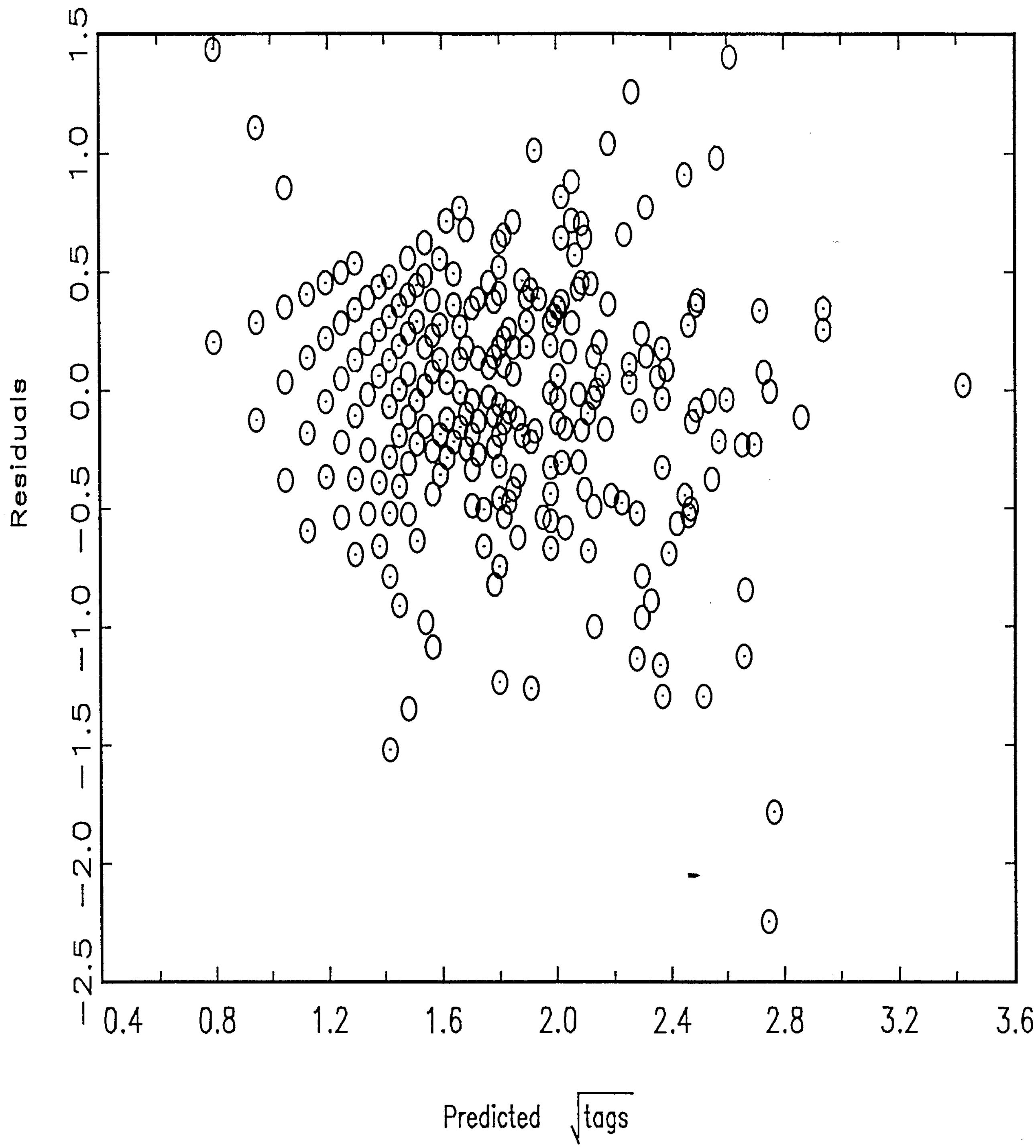

Figure A5. Plot of residuals from squafe-root transformed data.